Incremental Test Protocol, Recovery Mode and the Individual Anaerobic Threshold

T. M. McLellan, K. S. Y. Cheung, I. Jacobs

Environmental Physiology Section, Biosciences Division, Defence and Civil Institute of Environmental Medicine, P. O. Box 2000, Downsview, Ontario, Canada M3M 3B9

Abstract

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The individual anaerobic threshold (IAT) is defined as the highest metabolic rate at which blood lactate (LA) concentrations are maintained at a steady-state during prolonged exercise (15). The purpose of this study was to compare the effects of active and passive recovery on the determination of IAT following both a submaximal or maximal incremental exercise test. Seven males ($\dot{V}O_2max = 57.6 \pm 5.8$ ml·kg^{-1}·min^{-1}) did two submaximal, incremental cycle exercise tests (30 W and 4 min per step) and two maximal incremental tests. Blood was sampled repeatedly during exercise and for 12 min during the subsequent recovery period, which was passive for one submaximal and one maximal test and active (~ 35% $\dot{V}O_2max$) during the other tests. An IAT metabolic rate and power output were caclulated for the submax-passive (IAT_{sp}, $LA = 1.85 \pm 0.42$ mmol·l^{-1}), max-passive (IAT_{mp}, $LA = 3.41 \pm 1.14$ mmol·l^{-1}), submax-active (IAT_{sa}, $LA = 2.13 \pm 0.45$ mmol·l^{-1}) and max-active (IAT_{ma}, $LA = 3.44 \pm 0.73$ mmol·l^{-1}) protocols. At weekly intervals, the subjects exercised for 30 min at one of the four IAT metabolic rates. Active recovery did not affect the calculation of IAT, but following the maximal incremental tests, IAT occurred at a higher ($p < 0.05$) power output, absolute $\dot{V}O_2$ and % $\dot{V}O_2max$ (71% $\dot{V}O_2max$) compared with the IAT determined with the submaximal incremental tests (61% $\dot{V}O_2max$). During the 30-min IAT_{mp} and IAT_{ma} rides, LA and pH did not change significantly during the final 15 min, but LA values were higher (4.65 ± 0.62 and 5.20 ± 1.30, respectively) and pH lower (7.31 ± 0.02 and 7.30 ± 0.06, respectively) compared with the IAT_{sp} and IAT_{sa} rides (2.40 ± 0.77 and 2.90 ± 0.78, respectively for LA and 7.36 ± 0.03 and 7.35 ± 0.03, respectively for pH). The results demonstrate that for these subjects the calculated IAT is not affected by an active recovery period but the IAT occurred at a higher metabolic rate following a maximal compared with a submaximal incremental exercise test.

Key words

Blood lactate, exercise, metabolism, steady-state

Introduction

Stegmann et al. (15) defined the individual anaerobic threshold (IAT) as the metabolic rate where the elimination of blood lactate (LA) during exercise is both maximal and equal to the rate of diffusion of LA into the blood. The calculation of IAT involves the measurement of blood LA during a stepwise increasing exercise test followed by a passive recovery period. According to the original description of the IAT (15), the time during recovery when the blood LA concentration equals the value measured at the end of the highest exercise intensity is assumed to represent a time when the elimination of LA is maximal and equal to the rate of diffusion. A line drawn from this time during the recovery period that tangents the exercise blood LA curve will produce a time coordinate and, therefore, a power output that defines the IAT (see Fig. 1). Data presented for one subject by Stegmann et al. (15) showed that the determination of the IAT was not influenced by an incremental test that ended at 250, 300 or 350 watts.

Following intense exercise, active recovery increases the absolute rate of decline in blood LA values compared with passive recovery (1, 2, 9). In addition, the absolute rate of LA removal during recovery is directly related to the initial LA concentration at the end of exercise (7). Previously, findings from our laboratory revealed that an active recovery period at approximately 35% $\dot{V}O_2max$ influenced the calculation of IAT in untrained subjects (11). The IAT increased from 60% to 65% $\dot{V}O_2max$ when the submaximal incremental exercise test was followed by an active rather than a passive recovery period. The extent that active recovery influenced the calculation of IAT was directly related to the final intensity,

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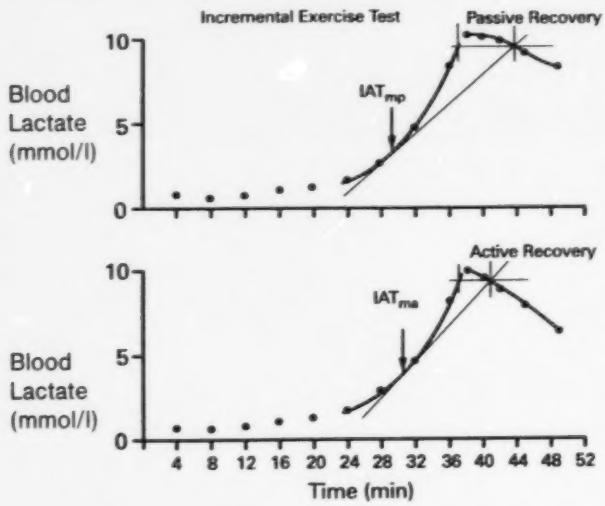

Fig. 1 One subject's data that shows the calculation of the individual anaerobic threshold (represented by the arrow) with passive and active recovery following a maximal incremental exercise test.

and therefore the blood LA concentration of the submaximal incremental test. Following an 8-week endurance-training program, however, active recovery did not affect the determination of IAT. One possibility suggested to explain these data focussed on the submaximal incremental test used to determine IAT. Since IAT increased following the training program when expressed relative to the changes in $\dot{V}O_2$max (i. e., IAT increased from 60% to 66%$\dot{V}O_2$max), it was possible that the submaximal incremental test did not end at a metabolic rate that was high enough above IAT to allow an active recovery period time to influence the determination of IAT.

In theory, exercise at power outputs above IAT will result in a progressive metabolic acidosis (16) and exercise time to exhaustion should be inversely related to the amount that the exercise work rate exceeds IAT (16). It would be worthwile, therefore, to know whether the incremental exercise protocol should continue to maximum and what recovery mode should be used to define a metabolic rate that corresponds to an individual's maximal exercise steady-state blood LA response. As a result, the purpose of the present investigation was to compare the influence of active and passive recovery on the determination of IAT following both a submaximal and maximal incremental exercise test. It was hypothesised that active recovery would have a greater influence on the calculation of IAT if the incremental test proceeded to maximum rather than ending at a submaximal power output.

Methods

Subjects

Following the approval of the Institute's Ethics Committee, written informed consent was obtained from seven male subjects (23.1 ± 2.3 yrs, 71.1 ± 7.3 kg, 1.77 ± 0.08 cm, with a $\dot{V}O_2$max of 57.6 ± 5.8 ml·kg^{-1}·min^{-1}) who volunteered to participate in the study. Subjects were instructed not to consume any food or beverage for at least 4 h before each testing session. A minimum of 48 h separated exercise tests which were performed at the same time of day for a given subject.

Incremental Exercise Tests

Subjects performed two submaximal and two maximal incremental exercise tests on a mechanically braked cycle ergometer (Cardionics, Stockholm). These tests involved continuous exercise which began at 60 W and increased every fourth minute by 30 W. All subjects performed a maximal incremental test followed by a passive recovery period for their first trial. The submaximal incremental tests proceeded to one power output increment above the IAT determined from this first maximal incremental test. The order of the two submaximal and the second maximal incremental trials was randomized among subjects. Blood samples taken from a hyperemic earlobe during the last 30 seconds of each power output increment were immediately assayed for whole blood LA with an automatic analyzer (YSI Model 23A). One submaximal and the first maximal incremental exercise test were followed by a period of complete rest (passive recovery), whereas following the other two incremental tests subjects continued to exercise at 35% $\dot{V}O_2$max (active recovery). Blood samples were taken at 1, 3, 5, 8 and 12 min of recovery. Approximately 60 min following the completion of the first incremental test with passive recovery, a 37.5 W·min^{-1} incremental test protocol was used to determine $\dot{V}O_2$max. From the power output, oxygen consumption ($\dot{V}O_2$)relationship observed during the first incremental test, the power output equivalent of 35% $\dot{V}O_2$max was calculated and used for those trials that were followed by an active recovery period.

Determination of IAT

Individual data points for both the exercise and recovery LA values were plotted as a continuous function against time (Fig. 1). The increasing portion of the exercise LA curve was fit with a single exponential function. The recovery LA curve was fit with a third order polynomial which minimized the residual sum of squares. The residual variance was less than 3% during exercise and 1% during recovery with the use of the mathematical functions described above. From the equation describing the recovery LA curve, the time associated with a LA value equal to the end of exercise LA was calculated. Once the values of these time, LA coordinates in the recovery period were known, time and LA coordinates could be calculated that defined IAT. The IAT coordinates satisfied the equation describing the exercise LA curve; in addition, the IAT coordinates were defined by a line passing through the recovery coordinates, with the slope of this line also defining the slope of a tangent to the exercise LA curve. We have reported previously that the test-retest reliability for the determination of IAT is 0.99 (6).

Prolonged Exercise Tests

The time coordinate describing IAT from the submax-passive (IAT_{sp}), submax-active (IAT_{sa}), max-passive (IAT_{mp}) and max-active (IAT_{ma}) protocols was converted to power output and $\dot{V}O_2$ since a linear relationship was observed among these variables during the incremental exercise tests. Subjects then exercised for 30 min at the power output equivalents of IAT_{sp}, IAT_{sa}, IAT_{mp} and IAT_{ma}. The order of these

Table 1 Variables associated with the individual anaerobic threshold (IAT) determined with either passive or active recovery following a submaximal or maximal incremental exercise test

	Incremental test and recovery protocol			
	Submax-passive	Submax-active	Max-passive	Max-active
%$\dot{V}O_2$max at end of incremental test	73.7 (5.2)	75.5 (3.5)	95.4* (4.9)	94.5* (4.7)
Blood lactate (LA) at end of incremental test (mmol·l^{-1})	3.53 (0.95)	3.99 (1.07)	8.04* (1.22)	7.30* (1.76)
Time during recovery for LA to equal end-of-exercise value (min)	2.34 (1.76)	1.79 (0.73)	3.91 (2.33)	3.13 (1.35)
Power output at IAT (watts)	174.5 (30.4)	180.3 (30.7)	205.4* (40.5)	205.9* (29.8)
Blood LA at IAT (mmol·l^{-1})	1.85 (0.42)	2.13 (0.45)	3.42* (1.14)	3.44* (0.73)
$\dot{V}O_2$ at IAT (l·min^{-1})	2.48 (0.45)	2.60 (0.48)	2.92* (0.65)	2.95* (0.52)
%$\dot{V}O_2$max at IAT	60.4 (4.8)	63.3 (4.4)	70.8* (6.9)	71.9* (5.5)

Values are mean (SD). n = 7; *Significantly different from submax-passive and submax-active protocols.

trials for each subject was identical to the order selected for the incremental exercise tests. Blood samples were taken at 5-min intervals from a 21-gauge catheter (Surflo) inserted into a dorsal hand vein. The technique of heating the hand and forearm in a heating chamber to obtain arterialised venous blood samples has been described previously (10). A 0.5 ml whole blood sample was immediately analysed for LA. An additional 1.0 ml sample was collected in a heparinised plastic syringe. This blood sample was immediately capped, placed in an ice bath and analysed immediately following the 30-min exercise trial for pH and pCO_2 by a pH and blood gas analyser (Corning 168), which had been calibrated previously with precision buffers and gases of known composition. Core temperature was monitored throughout exercise from a rectal probe, which was inserted approximately 12 cm beyond the anal sphincter. Changes in rectal temperature were used to correct pH and pCO_2 values to 37 °C.

Gas Exchange Analyses

For all testing sessions, subjects breathed through a low-resistance Hans-Rudolf respiratory valve. Expired gases were directed into a 5-l mixing box and through an Alpha Technologies VMM 110 Series Ventilation Module for the determination of minute ventilation ($\dot{V}_E$). A sampling line directed dried gases from the mixing box to a S-3A O_2 and CD-3A CO_2 Applied Electrochemistry analyzer. The gas analysers were calibrated before each test with a precision-analysed gas cylinder with known O_2 and CO_2 composition while the ventilation module was calibrated with a syringe of known volume. After conversion of the analogue voltage outputs from the ventilation module and the gas analyzers into digital signals (Hewlett-Packard 59313 A/D Converter), $\dot{V}_E$, carbon dioxide output ($\dot{V}CO_2$) and $\dot{V}O_2$ were calculated and printed on-line every 60 s using appropriate software on a Hewlett-Packard 9825A microcomputer. Heart rate was monitored by telemetry (Sport Tester, PE 3000) and recorded during the last 15 s of each power increment of the incremental exercise tests and at 5 min intervals throughout the prolonged exercise tests.

Data Analyses

A two-factor (incremental test and recovery mode) repeated measures ANOVA was performed on variables associated with the IAT determined from the different incremental test protocols. A repeated measures ANOVA was also used to compare gas exchange, blood LA, pH and pCO_2 responses during the prolonged exercise tests. Since one subject was unable to complete the 30-min exercise session at IAT_{mp}, data comparisons among the four IAT rides were calculated for six subjects. An additional repeated measures ANOVA was used to compare the LA value that represented IAT from the incremental test with the LA values measured during the 30-min exercise session at IAT. When a significant F-ratio was obtained, a Newman-Keuls post-hoc comparison was made to clarify the differences among treatment means. For all statistical analyses, the 0.05 level of significance was used.

Results

The IAT occurred at a higher power output, blood LA, absolute $\dot{V}O_2$ and %$\dot{V}O_2$max with the maximal incremental test protocols compared with the submaximal tests (Table 1). Active recovery did not influence the determination of IAT for either the submaximal or maximal incremental test trials (Table 1). As a result, corresponding gas exchange measures and changes in blood LA, pH and pCO_2 did not differ during the 30-min prolonged exercise tests between IAT_{sp} and IAT_{sa} nor between IAT_{mp} and IAT_{ma}.

The changes in $\dot{V}O_2$ through the prolonged exercise tests are presented in Fig. 2. During all tests, $\dot{V}O_2$ increased significantly during the initial 10 minutes. Although $\dot{V}O_2$ did not change over the last 15 minutes of the test, the 10-

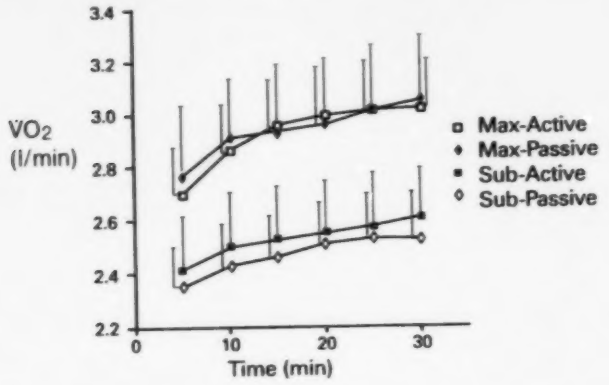

Fig. 2 Changes in mean values ± SD for oxygen consumption ($\dot{V}O_2$) throughout the 30-min prolonged exercise tests at the individual anaerobic threshold determined with passive and active recovery following a submaximal (sub) or maximal (max) incremental exercise test (n = 6).

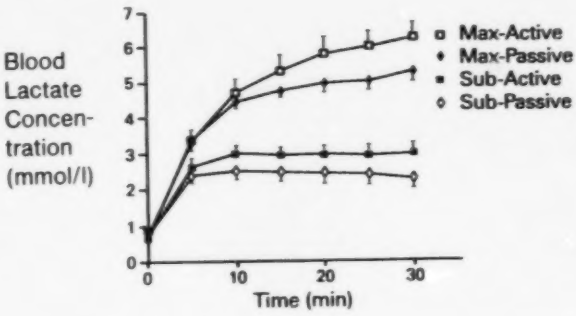

Fig. 3 Changes in mean values ± SD for blood lactate throughout the 30-min prolonged exercise tests at the individual anaerobic threshold determined with passive and active recovery following a submaximal (sub) or maximal (max) incremental exercise test.

min value was significantly less than the 30-min value for each test. The $\dot{V}O_2$ during the IAT_{mp} and IAT_{ma} tests was significantly different from the IAT_{sp} and IAT_{sa} values, reflecting the higher power outputs of the IAT determined from the maximal incremental test protocols.

During the IAT_{sp} and IAT_{sa} tests, $\dot{V}_E$ increased significantly from minute 5 (50.6 ± 8.4 and 53.2 ± 11.3 $l \cdot min^{-1}$, respectively) to 30 (54.3 ± 11.0 and 59.0 ± 18.0 $l \cdot min^{-1}$, respectively). In contrast, $\dot{V}_E$ was higher at 5 min for the IAT_{mp} (62.5 ± 17.6 $l \cdot min^{-1}$) and IAT_{ma} tests (62.2 ± 12.7 $l \cdot min^{-1}$) and increased at a faster rate throughout the 30-min session (78.6 ± 25.8 and 82.2 ± 15.7 $l \cdot min^{-1}$ for the IAT_{mp} and IAT_{ma} tests, respectively at 30 min).

Blood LA values during the four prolonged exercise sessions are presented in Fig. 3. For each 30-min test, the 5-min LA value did not differ from the LA value associated with the IAT determined during the incremental test (compare Table 1). However, during the remainder of the prolonged exercise tests (except for IAT_{sp}), LA values were increased compared with the value determined with the incremental protocols. Blood LA values did not change from minute 5 to 30 for the exercise tests at IAT_{sp} and IAT_{sa}. Blood LA values were significantly higher throughout the IAT_{mp} and IAT_{ma} tests compared with the IAT_{sp} and IAT_{sa} data. In addition, LA values increased significantly throughout the initial 10 minutes of the IAT_{mp} and IAT_{ma} trials. Thereafter, LA values did not increase for the IAT_{mp} test. For the IAT_{ma} trial, the 10-min value was significantly different from the 30-min value, but LA levels were not significantly different during the last 15 minutes.

Blood pH decreased to lower values during the IAT_{mp} (7.305 ± 0.016) and IAT_{ma} (7.297 ± 0.070) rides compared with the IAT_{sp} (7.359 ± 0.031) and IAT_{sa} trials (7.355 ± 0.033). For all prolonged exercise tests blood pH did not change during the last 20 minutes. Similarly, blood pCO_2 was significantly lower during the IAT_{mp} (36.2 ± 3.9 mmHg) and IAT_{ma} (35.8 ± 1.9 mmHg) tests compared with the IAT_{sp} (39.9 ± 3.8 mmHg) and IAT_{sa} (39.9 ± 2.3 mmHg). Blood pCO_2 decreased during the initial stages of each test but remained constant during the last 20 minutes of each exercise trial.

Discussion

It has been suggested that the metabolic rate that represents an individual's maximal steady-state for LA may have important implications for training and/or explaining differences in endurance performance among athletes with similar $\dot{V}O_2$max values (3, 10). Other exercise protocols have been described that define a maximal steady-state LA response for prolonged exercise (13, 14). These procedures, however, are conducted over a period of many days as a subject's exercise response is evaluated at different metabolic rates. The interpretation of adaptations that occur with training, for example, may be confounded by the length of time required by these other procedures (13, 14) to define an individual's maximal steady-state LA. It would be advantageous, therefore, if a single exercise test could be used to calculate such an exercise intensity. The determination of the IAT can be completed in one laboratory session. The present study was designed, therefore, to investigate whether this one exercise session should include a submaximal or maximal incremental exercise test followed by an active or passive recovery period.

The results from the present investigation have shown that an active recovery period at approximately 35% $\dot{V}O_2$max did not influence the determination of IAT, regardless of whether or not blood LA concentration at the end of the test was relatively high or low. These data are in contrast to findings we have previously reported for untrained individuals but are in agreement with the results obtained following an 8-week endurance-training program (11). The results from the present study also revealed that a higher IAT was calculated when a maximal incremental exercise test was used than when a submaximal incremental test was performed. These results do not agree with the data presented by Stegmann et al. (15) for one untrained subject.

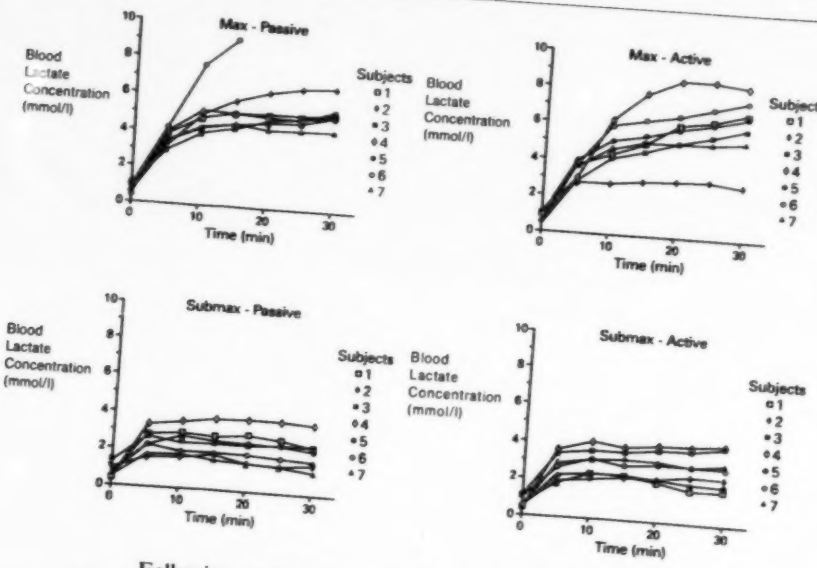

Fig. 4 Individual data for changes in bloo lactate throughout the 30-minute exercise test at the individual anaerobic threshold (IAT) determined with either a maximal (max) or submaximal (submax) increments test followed by either passive or active recovery

Following an intense exercise bout, an active recovery period increases the absolute rate of decline in blood LA values compared with a passive recovery period (1, 2, 9). This effect, however, is apparently negligible during the first few minutes of recovery in trained individuals (11). The subjects in the present study were regularly active, as reflected by an above average maximal aerobic power (mean $\dot{V}O_2max = 58$ $ml \cdot kg^{-1} \cdot min^{-1}$). As a result, the active recovery period did not significantly decrease the time required before the LA value in recovery equalled the end-of-exercise value (see Table 1). The determination of IAT, therefore, was not affected by the recovery mode. It should be noted, however, that for all subjects blood LA values were significantly lower during the later stages of the active recovery period compared with the passive recovery protocol (for example, see Fig. 1).

It is difficult to explain the influence of a maximal compared with a submaximal incremental exercise test on the calculation of IAT. Blood lactate concentrations alone cannot answer whether the rate of appearance or disappearance of lactate was affected more by the maximal exercise test and subsequent recovery period. The rate of disappearance of blood LA is function of the arterial concentration, blood flow to the tissues capable of metabolizing LA and the fractional removal per unit of flow (4). As LA concentration increases, the fractional removal decreases (7), but this inverse relationship is not linear. Since both LA concentration and blood flow would be increased following the maximal compared with the submaximal incremental exercise test, it is possible that the rate of disappearance of LA was also increased during the early minutes of recovery. As a result, the time required before the LA value in recovery equalled the end-of-exercise value would occur earlier than would be expected from the rates of disappearance of LA observed following the submaximal exercise test, and the calculated IAT would occur at a higher metabolic rate. This explanation is only speculative and tracer studies which have been used in the past for human exercise experiments (5, 7, 8) probably are necessary to clarify the relationship between the rate of appearance and disappearance of lactate with the different incremental test protocols and recovery modes used in the present investigation.

Statistical analyses of the mean data in the present study have shown that a maximal incremental test, regardless of recovery mode, could be used for the determination of IAT. However, individual data analyses for LA (Fig. 4) suggest that the IAT determined with the maximal test and passive recovery was a better protocol than the maximal incremental test with active recovery. Throughout the 30-min of exercise at the IAT determined with this latter protocol, four of the seven subjects had blood LA values that progressively increased. In contrast, only one subject failed to stabilize LA values during the last 15 min of exercise at the IAT determined with the maximal test and passive recovery. Therefore, we would recommend the use of a maximal incremental test followed by passive recovery for the determination of IAT in trained subjects. A light active recovery work rate, however, should be used during the post-exercise blood sampling period for IAT determination if the subjects are untrained (11) and not accustomed to maximal exercise tests.

There are additional methodological concerns about the IAT that warrant further investigation. For example, we cannot explain why the IAT power output determined with the max-passive protocol for one subject was clearly overestimated and led to exhaustion in 18 minutes. Similar concerns have been raised recently by Orok et al. (12). Also, if the IAT determined with a max-passive protocol truly represents a valid estimate of IAT, then exercise at power outputs slightly above this estimate should not result in steady-state LA values. From the present study we conclude that both the submax-passive and submax-active protocols do not produce a valid estimate of IAT since steady-state LA levels are evident during exercise at higher power outputs. Orok et a. (12) have questioned the validity of the IAT concept because LA values during constant-load exercise were increased compared with those measured at the same power output during an incremental exercise test. Similar findings were observed in this investigation. However, we do not feel these results invalidate the IAT. Stegmann et al. (15) defined IAT as the metabolic rate that produced maximal steady-state LA levels. The disparity between LA values measured during a 4-min, 30 W incremental test and values measured during 30-min constant-load exercise reflects the difference in the time constants for the turnover and clear-

ance of lactate. The extent that these processes differ during an incremental test will be reflected in the shape of the recovery LA curve, and the time required before the LA value equals the end-of-exercise value. The concept of the IAT does not mean that steady-state LA levels will be reached in 3 or 4 minutes but rather that maximal steady-state values will be achieved. Invariably, the maximal steady-state LA level will be higher than the value measured at the same power output during a 3- or 4-min step-incremental exercise test (16, the present study).

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T. M. McLellan

Defence and Civil Institute of Environmental Medicine
P. O. Box 2000
Downsview, Ontario
Canada M3M 3B9